(12) # EUROPEAN PATENT SPECIFICATION

(54) **Method of recognising an irradiation field**

Strahlungsfelderkennungsverfahren

Procédé pour la reconnaissance d'un champ de rayonnement

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'Segmentation and grouping of object
boundaries'

Description

Field of the invention.

5   Th present inv ntion is in the field of digital radiography. The invention more specifically relates to a method of recognising an irradiation field in a system wherein a radiation image is recorded on a photostimulable phosphor screen by means of an irradiation field stop (i.e. means for partially shielding against irradiation).

Description of prior art

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Radiologists may protect their subjects against unnecessary exposure to X-rays by use of X-ray opaque ('collimation') material. The material is placed in the path of the X-ray beam so as to shield those areas of the patient which are not regarded as diagnostically important. Besides reducing patient dose this technique has the additional advantage of limiting the amount of scattered radiation in the image field of interest. The regions of the resulting image which
15   comprise the shadow cast by the X-ray opaque material (shadow regions, cfr. example in figure 1) are exposed only by scattered radiation.

In computer-assisted radiology, the X-ray image is digitised as a two dimensional array of numbers, whose magnitude is related to the intensity of X-rays arriving at the detector, via the patient. The values in the array may be rescaled, prior to display or printing, in order to maximise the visual contrast in the area of diagnostic interest. Such
20   rescaling depends, in part, on the intensity histogram of the X-ray image. To achieve this function automatically, best results are obtained if the 'shadow' cast by the collimation material is excluded from consideration, since it cannot contain any useful information, but would otherwise dominate the lower end of the intensity histogram.

The presence of the collimation shadow region can cause an additional problem in the display of the image on film. Therein, the shadow region is relatively bright, and if displayed unmodified, may impair diagnosis of subtle lesions
25   due to dazzle, especially if the unexposed region is relatively large.

The U.S. patent 4,952,807 by Adachi addresses the first problem, wherein a method is disclosed for adjusting the image processing conditions by selecting only those pixels which correspond to the object or to the background, i.e. the 'signal' region, under the assumption that the collimation material does not partly cover the object, i.e. the shadow region does not touch the object of the image, but rather its surrounding background. In many kinds of examinations
30   however, parts of the patient will be shielded from exposure to avoid useless X-ray load, as is the case with lumbar spine and shoulder examinations.

The U.S. patent 4,804,842 from Nakajima also addresses the first problem, wherein a method is disclosed for removing the lower part of the histogram corresponding to the pixels in the shadow region in order to adjust the image processing conditions.
35   However, techniques for histogram modification alone, do not address the second problem, i.e. that of dazzle. Its solution demands an explicit detection of the shadow region, as distinct from the signal region. The offending shadow region may then be excluded from the display process. In addition, the first problem of rescaling for optimum visual contrast can then proceed on the signal region alone, without the complicating influence of the shadow region on the intensity histogram.
40   Previous work in the field of automatically delineating the signal/shadow regions has relied on piecemeal attempts at the solution.

Many of the proposed methods are based on collecting candidate signal/shadow border pixels (i.e. edge pixels at the interface between signal and shadow regions) by thresholding on first differences along predetermined lines that might cross the signal/shadow border. A typical example of this approach is proposed by Funahashi in the U.S. patent
45   4,970,393. The signal region is recognized as a region enclosed by pixels where the first difference exceeds some specified threshold, either positive or negative.

A refinement of this technique is proposed by Takeo in the European patent 0 342 379, where multiple candidate pixels along a searching line are ranked, and only the highest rank candidates on each searching line are considered in assembling the signal/shadow boundary. In both methods the underlying assumption is that the signal/shadow bound-
50   ary has strong contrast everywhere. In many cases however, contrast along parts of the signal/shadow boundary is nearly zero, especially if the collimation material is partially covering very dense parts of the body. So if the recognized signal/shadow boundary is assembled from high difference pixels many gaps will occur in general.

In the European patent 0 285 174 by Funahashi a straightforward application of the basic Hough transform technique is proposed to delineate the signal/shadow boundary, which is assumed to be polygonal. The Hough transform
55   is applied to prospective edge points obtained by differentiation.

The underlying assumptions are that th signal/shadow boundary is piecewise linear, and has high contrast with respect to the contrast of line features within the signal region. However, experimental evidence shows that edges within the signal region, e.g. bone edges, frequently have higher contrast than the signal/shadow boundary. As a consequence

points in Hough transform space that correspond to straight bone boundaries may have higher scores than some of the actual signal/shadow borders, in which case the subsequent delineation procedur will fail.

A diff rent approach is disclosed in the European pat nt 0 360 231 by Funahashi. The image is subdivided into mutually adjacent non-ov rlapping tiles. A statistical parameter is computed indicating the edge content of the tile, either by differentiation in image space, or in frequency space. The tiles are accordingly classifi d as b longing to the relevant image region or not.

We ran elaborate experiments and concluded that single criteria based on edge contrast, or local statistical parameters at both sides of a prospective signal/shadow boundary, such as mean value, min, max, variance or spatial frequency coefficients are inadequate in delineating the irradiated field with a high level of confidence, say > 98 percent. We found that the signal/shadow border contrast will vanish in some cases; anatomical structures may be straight and have high contrast edges; the image signal (which represents local dose) in the shadow region will occasionaly be higher than the signal in the unshielded (i.e. diagnostic) image region - in cases where the scattered radiation is high and some parts of the body are difficult to penetrate by radiation. Also we found that there is no essential distinction between image areas corresponding to very poorly penetrated bone, and areas corresponding to shielded parts. Both kinds of areas will be characterised by an extremely low mean value (i.e. dose), similar noise level (both quantum limited), and by the absence of other features (since the signal to noise ratio is very low).

In order to obtain a high success rate, a preferred method should consider many hypotheses as to the location of the signal/shadow boundary, and keep or reject each hypothesis "as a whole", instead of keeping or rejecting individual components of a hypothesis, such as edges.

Multiple hypotheses as to the location of the signal/shadow boundary are considered in the method disclosed by Tanaka in the U.S. patent 4,952,805. For each of the corresponding candidate signal regions, two signal histograms are computed: one for the pixels inside the candidate irradiation field and one for the pixels outside. The candidate boundary which is characterised by the largest degree of interclass separation as determined from both histograms is selected to be the recognised irradiation field.

The degree of interclass separation is defined in such a way that a high value will result if there is very little overlap between both histograms. Hence this criterion will be effective only if the range of signal values within irradiation field are well separated from the signal values in the shielded region, which does not hold in many practical cases as we verified on the basis of digital radiographs from various examinations.

Also, there is a practical limitation regarding the usability of the above mentioned approach, in that the number of hypotheses as to the location of the irradiation field may be prohibitively large.

Previous work in general has focussed on methods in which finding the boundary of an irradiation field essentially relies on a very small number of mostly local criteria. Reviewing a wide variety of examinations confirms that individual criteria will only work in a very limited number of cases. A high success rate can only be achieved if many sources of evidence are combined, ranging from local image features to global constraints.

The behaviour of the radiologist, in placing the collimation material around the patient, may broadly be characterised by a set of simple rules. This invention addresses only the use of collimation material which casts a shadow whose outline is piecewise linear. More specifically, the boundary between signal, and shadow regions is assumed to be a rectangle of arbitrary location and orientation. It is assumed that the signal region is on the interior, and that any part of the rectangular boundary may, or may not, have a projection onto the (rectangular) detector, and therefore the image array; see figure 1.

Objects of the invention

It is an object of the present invention to provide a method of recognising an irradiation field in a system wherein a radiation image has been recorded by using an irradiation field stop (collimation material).

It is a further object to provide a method for determination of the location of the signal/shadow boundary of an X-ray image, wherein the x-ray image is represented by a digital signal representation and wherein a signal/shadow boundary is the locus of interface between the signal and the shadow regions resulting from the obscuring by the collimation material.

It is a still further object to provide such a method in a system wherein a radiation image is recorded in a photo-stimulable phosphor screen and wherein said radiation image is read by scanning the screen with stimulating radiation and by detecting the light emitted upon stimulation.

It is still a further object of the present invention to aid the process of contrast-enhancement of an X-ray image, by permitting such to perform its calculations based solely on the diagnostically useful signal part of the X-ray image, and to reduce the brightness in shadow region to avoid dazzle during diagnosis.

Statement of the invention

The present invention provides a m thod for the determination of the location of th signal/shadow boundary in an X-ray image represented in a digital signal representation comprising the st ps of :

i) Extracting low-level primitives from the X-ray image {X(i,j)}, ii) Forming a reduced number of intermediate-level primitives from the low-level primitives,
iii) Building hypotheses being possible solutions regarding the location of the signal-shadow boundary from combinations of intermediate-level primitives, during which each combination is subject to intermediate-level tests, whereupon partial or complete hypotheses are rejected or accepted,
iv) Performing high-level verification tests on each hypothesis, whereupon hypotheses are rejected, or accepted at some cost said cost defining a ranking of the acceptability of a hypothesis,
v) Selecting the hypothesis with the least cost.

The method of the present invention is a major departure from earlier methods in that, in general, it generates many hypotheses as to the location of the boundary. The final decision as to the correct hypothesis is contingent on the results of a number of high-level tests applied to each.

The method permits codification of expert-system type knowledge as to the geometry, topology, and statistics of the signal/shadow boundary, and associated regions.

The invention is, for example, applicable to a digital image signal obtained by exposing a photostimulable phosphor screen to an image originating from a partially shielded exposure of an object to X-rays, by scanning the screen with stimulating irradiation, detecting the light emitted upon stimulation and converting the detected light into a digital signal representation.

Commonly the digital signal is subjected to image processing such as contrast enhancement and signal-to-density mapping before being applied to an output device for reproduction or display. The result of the process of contrast-enhancement of an X-ray image is enhanced by permitting such to perform its calculations based solely on the diagnostically useful signal part of the X-ray image, and to reduce the brightness in shadow region to avoid dazzle during diagnosis.

In the statement of the invention and in the description hereinafter the term "X-ray image " is used in the meaning of a two-dimensional digital image repesentation as an array of numbers, the magnitudes of which are directly related to the intensity of the X-rays arriving at a 2-dimensional physical detector such as a photo-stimulable phosphor screen.

By "primitives" is meant features, such as edges, which are extracted from the image as the result of low-level image processing, cfr. fig. 2.

An "intermediate-level primitive" is a combination of (basic) primitives which may be considered collectively when building a hypothesis. Intermediate-level primitives are generally fewer, and (spatially) larger than are (basic) primitives. Each primitive is constructed from a mutually exclusive set of pixels. Each intermediate-level primitive is constructed from a mutually exclusive set of (basic) primitives.

By the term "signal region" is meant the spatial area of an image which is not obscured by collimation material from a direct line-of-sight of the X-ray source, see figure 1b.

The "shadow region" is the area of the image which is obscured by the collimation material from a direct line-of-sight of the X-ray source; see also figure 1b.

The "signal-shadow boundary" is the locus of the interface between the signal and the shadow regions. E.g. the pixels at the interface between the signal and the shadow regions.

A low-level primitive can be a line - being a data structure to represent an edge, and associated data, including its parameterisation - or a tile - being a small rectangular area of pixel resulting from a tessellation of the image array.

Steps i) and ii) of the method of the invention achieve a reduced set of primitives which can be assembled into hypotheses as to the location of the signal-region.

A "hypothesis" is defined as a possible solution posited by the method of the present invention, said solution being a segmentation (division into similar regions) of the original image into signal and shadow regions, e.g. a two-dimensional array of numbers isomorphic with the X-ray image, with pixel labels for signal and shadow regions.

Hypotheses are generated from the reduced (intermediate-level) set because, in general, the number of low-level primitives is too numerous to perform an exhaustive evaluation (step iv) of every possible combination (step iii).

Specifically, if the low-level primitives are lines, then the intermediate-level primitives would be line-clusters, the result, for instance, of a linear agglomerative clustering process.

A line cluster is then one or more lines which are deemed to be in some manner similar, and hav been accordingly

grouped together.

E.g. one or mor lines which have been grouped together by a linear agglomerative clust ring process. In th example of figure 3, the lines 1b and 1c may be clustered togeth r to form a line clust r {1b,1c}. Similarly, in the same example, the likely clusters are {1a}, {1d}, {1e, 1f, 1g}.

Alternatively, a low-level primitive can be a tile, i.e. a small rectangular array of pixels resulting from a tessellation of the image array. In this case an intermediate-level primitive would be a tile-cluster, being a group of spatially connected tiles having in common a feature or an attribute.

Step iii) combines the intermediate-level primitives into complete hypotheses posited by the system.

The definition of the word "hypothesis" was given hereinbefore, by which term is meant a possible solution regarding the shape and position of signal and shadow regions.

Such a solution is a segmentation or division of the image into signal and shadow regions.

One of the possible representations of such a segmentation is a two dimensional array of numbers, isomorphic with the X-ray image, the values of which represent a unique label which identifies the corresponding region in the X-ray image as either signal or shadow region.

A label generally is a pixel-value which associates the pixel, i.e. the location in the image array, with a particular class (having a particular quality or attribute).

In order to limit the number of hypotheses to be submitted for evaluation (step iv), the method includes provision for tests which may be applied during the construction of the hypothesis, which serve to detect and reject, at an early stage, an incorrect hypothesis.

Specifically, if the intermediate-level primitives are line-clusters for instance, then a possible test is on the mutual orthogonality of the line-clusters as putative sides of the signal/shadow border. Thus combinations of line-clusters which are not going to form a rectangle can be rejected at an early stage.

Step iv) permits the evaluation of hypotheses successfully assembled from the intermediate-level primitives. A major feature of this invention is the generation of multiple hypotheses, where in each hypothesis is a candidate for the complete signal/shadow boundary. The high-level tests permit evaluation of each hypothesis, specifically of those attributes which can only be determined once a complete signal/shadow boundary is hypothesised. By such high-level tests, hypotheses at this level may be ranked (or possibly rejected) in order that a single candidate may eventually be chosen.

Specifically, the ranking of hypotheses may be based on a scalar quantity representative of either the net positive or negative evidence in favour of, or against that hypothesis. The distinction is immaterial: the highest ranking hypothesis is that most like the idealised model. In the former case this will have the largest (positive score), in the latter: the smallest negative score.

The evidence may be based on any of a number or combination of primitives, and less local features of the original X-ray image. For instance, negative evidence may be accumulated against a candidate signal/shadow boundary for each corner of the signal/shadow boundary according to (a monotonic function of) the magnitude of the difference of the angle at the corner from 90 degrees. Such a test would attempt to enforce the rectangular geometry of the model.

Broadly, tests may seek to enforce the geometry, topology, region statistics, and edge statistics required by the model. Within these categories, other possible sources of evidence may involve tests for:

Edge statistics:

- Linearity: The straightness for each of the candidate signal/shadow boundary sides (however they were achieved).
- Existence: The accumulated evidence along the length of each side, computed from an edge-image, such as that furnished by Canny edge-detection for instance.
- Continuity: The length of each candidate signal/shadow boundary side for which there exists no evidence from the edge-detection process.
- Explanation: The ratio of used evidence to the total evidence. In this context, the evidence is the number of edge-pixels.

The used evidence is the number of edge pixels in the signal/shadow boundary.

The unused evidence is the number of edge pixels which lie on edges outside of, but colinear with, those edges deemded to be in the candidate signal/shadow boundary.

Geometry:

- Proportion: The aspect ratio of the rectangle (perhaps favouring rectangles with an aspect ratio similar to that of the X-ray image).
- Area: The area of the candidate signal-region (perhaps penalising very small rectangles).
- Position: The placement of the centre of the candidate rectangle (perhaps favouring rectangles with their centre near the centre of the X-ray image).
- Orientation: The orientation of the candidate rectangle within the image (perhaps favouring rectangles parallel with the edge of the X-ray image).

Region statistics:

- Exposure: The mean, maximum, minimum (and the like) statistical measures derived from the (candidate) signal and shadow regions of the X-ray image (perhaps favouring low-exposure grey-levels in the shadow, versus signal regions).
- Homogeneity: The variance (and the like) statistics derived from the (candidate) signal and shadow regions of the X-ray image (perhaps favouring low-variance grey-levels in the shadow, versus signal regions).

Topology:

- Visibility: The visibility of the candidate signal/shadow boundary, i.e. the degree to which the candidate signal/shadow boundary is wholly contained within the image (perhaps favouring complete, rather than clipped boundaries - eg as in figure 1d rather than fig. 1e).
- Completeness: The number of visible rectangle sides.

Hypotheses consisting of just two 'sides' (which are approximately orthogonal or parallel), can be considered as partially visible rectangles. The scoring may, for instance, favour hypotheses with more, over fewer, sides.

The scalar result of each test may provide for the rejection of a hypothesis by assuming an appropriately small positive or large negative value, effectively denying that hypothesis any chance of highest ranking.

Step v) is just the selection of that hypothesis which is ranked the highest of those surviving the high-level tests of step iv).

The method of the present invention can be applied for recognising an irradiation field in cases where at the exposure step an irradiation field stop has been used.

It will be clear that the invention is not limited to this particular application. It can for example also be used when the borders of irradiation fields have to be determined in an application wherein at least two images are recorded in a juxtaposed relation, a mode often referred to as 'split screen'.

Brief description of drawings

The method of the present invention as well as particular embodiments hereof will be explained hereinafter with reference to the accompanying drawings wherein

Figure 1 shows examples of location, orientation, and visibility of signal/shadow boundary,

Figure 1a shows an image with no collimation shadow regions,
Figure 1b shows an image wherein two sides of the rectangle are visible, (1) is the signal region, (2) are the shadow regions,
Figure 1c shows an image with 3 sides of the rectangle visible,
Figure 1d shows an image with all 4 sides of the rectangle visible,
Figure 1e shows an image wherein 4 sides are partially visible,
Figure 1f shows an image with 1 side visible,

Figure 2 is an example of Canny Edge Detection,
Figure 3 is an example for line clustering. Lines l_b and l_c may be clustered. Similarly, lines l_e, l_f and l_g may be clustered.
Figure 4 is an example of edge thinning,
Figure 5 are examples of vertex classifications for the central pixel in each 3x3 array,

The following is a detailed description of each of the individual method steps of the present invention.

Step i) Extraction of low-level primitives

The preferred low-level primitives are lines. They are derived from the X-ray image in two stages: edge-detection and segmentation.

1.1 Edge Detection

The purpose of this stage is to produce an edge-image: see for example figure 9a. Our system incorporates a Canny edge-detection process.

The following are definitions of some terms used in connection with a Canny edge detection process:

Canny edge-detection: A particular process for edge-detection comprising optional smoothing, followed by production of an edge-image wherein a pixel is labelled as an edge-pixel if and only if the Sobel squared magnitude at that point is a local maximum along the (one-dimensional) trajectory which is normal to the Sobel orientation.

A Canny edge-image $\{E(\underline{r})\}$ is formed by non-maximal suppression of the Sobel squared magnitude in the direction of the orientation of the image gradient, i.e. normal to the Sobel orientation:

$$E(\underline{r}) = 1 \text{ if } G(\underline{r}) > G(\underline{r}+\underline{R}_q) \geq G(\underline{r}-\underline{R}_q)$$

$$= 0 \text{ otherwise}$$

where

$$\underline{R}_q = (1,0) \text{ if } ||Q(\underline{r})| - \pi/2| \leq \pi/8$$

$$= (1,-1) \text{ if } ||Q(\underline{r})+\pi/4|- \pi/2| < \pi/8$$

$$= (1,1) \text{ if } |Q(\underline{r})+\pi/4| < \pi/8$$

$$= (0,1) \text{ if } |Q(\underline{r})| \leq \pi/8$$

Let $\underline{a}$ mean a is bold and vectors $\underline{r}$, $\underline{R}_q$ represent the two-dimensional coordinates on the image plane ($\underline{r} \equiv (i,j)$ say). For an illustration, see figure 2.

Smoothed image: An intrinsic image derived from the X-ray image wherein the high spatial frequencies are suppressed relative to the low spatial frequencies. E.g. the result of convolution of the X-ray image with a (two-dimensional) Gaussian.

Sobel squared magnitude: The pixel-value $G(i,j)$ representing the square of the gradient-magnitude of the image $\{X(i,j)\}$ as determined by the following formula:

$$G(i,j) = (X(i+1,j) - X(i-1,j))^2 + (X(i,j+1) - X(i,j-1))^2$$

Sobel orientation: The pixel-value Q(i,j) representing the orientation of the tangent to the iso-gradient-magnitude of the image {X(i,j)}, as determined by the following formula:

$$Q(i,j) = atan2(X(i+1,j) - X(i-1,j), X(i,j+1) - X(i,j-1))$$

where atan2(y,x) is the arctangent C language function defined in $[-\pi, \pi]$.

The edge-detection process incorporated in our system comprises four stages:

1.1.1 Subsampling of the X-ray image

The subsampling reduces the number of pixels of an image. For example: an original image obtained by reading an irradiation image stored in a photostimulable phosphor screen (cfr. figure 12) comprising approximately 5 million pixels, is reduced to an image of about 20000 12-bit pixels, preserving the aspect ratio of the original image.

1.1.2 Canny Edge-Detection

The subsampled image is passed to a Canny edge-detector to produce images: Sobel-squared magnitude {G(i, j)}, Sobel-orientation {Q(i,j)}, and edge-image {E(i,j)}. The Gaussian smoothing is via a symmetric 5x5 convolution mask with weights calculated to effect a standard deviation of 0.35 pixels.

1.1.3 Elimination of Weak Edges

Edge-points with a low gradient magnitude indicate a weak edge. Studies have shown that the signal/shadow boundary is generally of high contrast, giving a large gradient magnitude. Very weak edges are therefore unlikely to form part of the signal/shadow boundary. Those with a Sobel-squared-magnitude below a threshold of 2000 are removed from {E(i,j)}, and correspondingly from {Q(i,j)}, and {G(i,j)}.

1.1.4 Angle of Locus

The orientation {O(i,j)}, of the locus of edge-points in the edge-image {E(i,j)}, is calculated in three stages: edge-thinning, connectivity analysis, linear regression.

1.1.4.1 Thinning

The edge-image is destructively thinned. The motivation is threefold:

1. The parameters of a regressed straight line, including the goodness-of-fit, are more accurately determined from the spatial distribution of edge-points.
2. The various types of junction (TERMINAL, T-JUNCTION, ...) are more easily detected. This is required for corner-detection (below).
3. There then exists a close correspondence between the length of a straight line, and the number of (connected) edge-pixels of which it is made up. This is required for line-statistics (above).

Thinning is achieved by removing edge-pixels which do not affect the local (3x3) connectivity of other edge-pixels. See figure 4 for an example.

1.1.4.2 Connectivity Analysis

Connected edges are uniquely labelled by recursive edge-walking to create a label image {L(i,j)}. All edge-pixels mutually connected share a common, but otherwise unique, label.

1.1.4.3 Linear regression

In this connection the following definitions are first given:

- Linear regression: The process by which an edge can be optimally parameterised according to the spatial location of its constituent edge-pixels. E.g. the determination of the parameters of a line which are the radius to the normal

(from the origin), and its orientation r lative to the X-axis, by a least squares (of perp ndicular distances) fit.

- W ighted linear regression: The proc ss by which an edge can b optimally parameterised according to both the spatial location of its constituent edg -pixels, and th degree of certainty as to th ir correct classification (labelling). E.g. the determination of the parameters of a line which are the radius R_{WLR} to the normal (from th origin), and its orientation Q_{WLR} relative to the x-axis, by the minimisation of a weighted least squares (of perpendicular distances) fit, the weighting being the Sobel squared magnitude.

Let p_k be the positions of the edge-pixels (indexed by k) which comprise the line:

$$p_k = (p_k^{(x)}, p_k^{(y)})$$

and let the positional covariance matrix be Γ:

$$\Gamma = \begin{bmatrix} \Gamma^{(x,x)}, & \Gamma^{(x,y)} \\ \Gamma^{(y,x)}, & \Gamma^{(y,y)} \end{bmatrix}$$

given by $\Gamma^{(a,b)} = \Sigma_k p_k^{(a)} p_k^{(b)} w_k - \Sigma_k p_k^{(a)} w_k \Sigma_k p_k^{(b)} w_k$ for a,b in {x,y} then $Q_{WLR} = 1/2 \operatorname{atan2}(-2\Gamma^{(x,y)}, \Gamma^{(x,x)} - \Gamma^{(y,y)})$ and $R_{WLR} = (\sin(Q_{WLR})\Sigma_k p_k^{(x)} w_k + \cos(Q_{WLR})\Sigma_k p_k^{(y)} w_k)/\Sigma_k w_k$ The eigenvalues λ_+, λ_- of Γ are the sum of square errors (i.e. proportional to the variances) in each of the principal directions ie along, and normal to, the best fit straight line:

$$2\lambda_{\pm} = Tr(\Gamma) \pm (Tr(\Gamma)^2 - 4Det(\Gamma))^{1/2}$$

In the described embodiment of the present invention the orientation of the locus at each point is calculated by linear regression of connected edge-points in a local neighbourhood (nominally 7x7). The connectivity is guaranteed by including only those pixels which, in {L(i,j)}, share a common label. The positional-covariance matrix gives the orientation of the maximum variance of the data which is also the orientation of the least-squares fit straight line with two degrees of freedom.

With reference to the definition of weighted linear regression, with $w_k=1$: $O(i,j)=Q_{WLR}$ is the orientation of the locus of edge-points without regard to the sense of the original edge. The ambiguity in the sense of the locus is resolved by borrowing from the Sobel orientation Q(r) : the direction of the tangent to the Sobel squared magnitude iso-contour is always close to the direction of the tangent to the locus of edge-points as determined by the Canny edge-detector.

Therefore the orientation is adjusted to minimise the angular separation between O(i,j) and Q(i,j):

$$\operatorname{Min} \{O(i,j) - Q(i,j) + k\pi\} \Rightarrow k_{min}$$

$$k \text{ in } \{-3..3\}$$

$$O(i,j) := O(i,j) - Q(i,j) + k_{min}\pi + 2n\pi$$

where n is chosen so that the result is in $[0,2\pi]$.

1.2 Segmentation

Line primitives are built from the remaining edges. The chains of edge-pixels are broken into piece-wise straight sections (figure 9b), and the pixels from each section assembled into a line structure.
There are four steps to this procedure:

1.2.1 Vertex Analysis

An intrinsic image {V(i,j)} is constructed with labels for the classification of edge-pixels in {E(i,j)}. According to th 3x3 connectivity of edge-pix ls in {E(i,j)}, one of the following labels are awarded to the corresponding point in {V(i,j)}: ISOLATED-POINT, TERMINAL, EDGE-POINT, T-JUNCTION, X-JUNCTION. An example of each is given in figure 5.

1.2.2 Corner Detection

Corners are detected by a refinement of the EDGE-POINT labels in {V(i,j)}. There are two stages:

1.2.2.1 Curve detection

An intrinsic image {U(i,j)} is calculated with values assigned to each pixel which corresponds to an EDGE-POINT labelling in {V(i,j)}. The pixel values in {U(i,j)} measure the local conformity of edge-pixels in {E(i,j)}, in a 7x7 neighbourhood, to a straight-line. The positional covariance matrix is calculated as described in 1.1.4.3 with all $w_k=1$.

The conformity, (to a straight line) is taken to be the ratio of major to minor eigenvalues of the positional covariance matrix, ie λ_+/λ_-. Pixels previously labelled as EDGE-POINTs in {V(i,j)} are then relabelled as CURVEs, if the conformity is less than a threshold value:

If V(i,j)=EDGE-POINT , and $\lambda_-\lambda_+ > 0.04$, then V(i,j) = CURVE.

1.2.2.2 Non-maximal supression

The pixels in {U(i,j)} are identified as corners if they are both CURVE points in {V(i,j)} (i.e. having a value above some threshold), and they are locally maximum in a 3x3 neighbourhood. The corresponding pixels in {V(i,j)} are relabelled as CORNERS.

1.2.2 Extraction of connected edges

Those pixels in {V(i,j)} still retaining an EDGE-POINT classification are candidates for incorporation into the low-level primitives. Such pixels are extracted from {V(i,j)}, into {S(i,j)} say, which is the linear segmentation as an intrinsic image: each connected chain of pixels is given a unique label in {S(i,j)}. Each connected set of pixels is then gathered into a line structure which is the low-level primitive.

1.2.2.1 Rejection of short lines

Studies have shown that sides of the signal/shadow boundary generally have at least some portion of their length for which the edge-detector furnishes an unbroken chain of edge-pixels. In order to avoid false positives therefore, an implicit rule is that a side cannot be composed entirely of very short edge-chains, but must have at least one line (in the line-group) which is of substantial length. Prior to segmentation and extraction of the line primitives therefore, chains of edge-pixels shorter than some threshold length are rejected (from {S(i,j)}) at this point. By this means, the number of low-level primitives is reduced without compromising the accuracy: short lines may form part of the final hypothesis following data-retrieval.

1.2.3 Weighted linear regression

A weighted linear regression is performed on each of the lines, by which means the optimal parameters (normal radius to origin, and orientation), and conformity are recorded. The weights are the Sobel-squared magnitudes of the contributing edge-pixels, as a fraction of the maximum Sobel-squared magnitude:

$$w_k(i,j) = G(i,j)/\text{Max} \{G(u,v)\} \ \forall \ i,j$$

$$\forall \ u,v$$

1.2.3.1 Rejection of poor lines

Lines are no longer 'local' entities. The test on conformity to a straight line is now repeated with a less tolerant threshold in accordance with the extra precision afforded by the (arbitrarily large) number of edge-pixels in the line:

1.2.4 Linear xtrapolation

The surviving lines are extrapolated from each end, until they intersect either the edge of the imag , or an edge-point which does not belong to that line (as determined from the labels in {S (i,j)}). The 'limits' so determined, are saved in the line structure. A distinction is made between each of the two limits which correspond to the two ends of the line. This distinction respects the sense of the line: see figure 6.

1.2.5 Data-retrieval

Edge-points are now recovered from {E(i,j)} which were not classified as EDGE-POINTs in {V(i,j)} (perhaps because they were reclassified as CORNERs, CURVEs or JUNCTIONs etc). For each line, two rectangular areas are scanned in {E(i,j)} each of which is centred on (aligned with) the projection of the line as given by the regressed parameters R_{WLR} and Q_{WLR}. The rectangles extend from the line end-points, to the limits as determined by extrapolation. The width of the rectangle is 5 pixels. All edge-points in {E(i,j)} which were not already attributed to the line are now included.

Step ii) Extraction of intermediate-level primitives

2.1 Linear agglomerative clustering

In this connection the following definition are given:

"Linear agglomerative clustering" generally is an iterative process for grouping together lines which are deemed (by some criteria) to be sufficiently similar. E.g. a pair-wise agglomerative clustering process based on an analysis of variance test, and broadly as described in "Unsupervised Estimation of Polynomial Approximations To Smooth Surfaces in Images or Range Data" by J.F. Silverman and D.B. Cooper, Proc. IEEE Conf. on Automation and Robotics, 1986, page 299-304. and defined hereinbelow, but with the mergable entities being lines rather than regions, and the constraint that two mergable regions be touching replaced by a constraint that two lines (or line-clusters) be linearly coherent.

"Analysis of variance" is a statistical method for comparing (the similarity of) two sample distributions under the assumption that the underlying distribution is Gaussian; but the variance is unknown. The method determines an F-statistic, which is the ratio of the two sample variances, correctly normalised to take account of the true degrees of freedom.

When the test is to determine the likelihood of two distributions having the same parent distribution, then the ratio is between the unexplained and the explained variances. When applied to pair-wise clustering, the unexplained variance is the extra that is incurred by the proposed merge:

$$<\sigma_u^2> = (\chi_m^2 - \chi_a^2 - \chi_b^2)/|v_m - v_a - v_b|$$

where a,b and m denote the separate, and merged entities respectively; χ and v are the chi-squared variates and corresponding degrees of freedom. The explained variance is that prior to the proposed merge:

$$<\sigma_e^2> = (\chi_a^2 + \chi_b^2)/(v_a + v_b)$$

and

$$F(v_u, v_e) = <\sigma_u^2>/<\sigma_e^2>$$

is the F statistic, having degrees of freedom

$$v_u = |v_m - v_a - v_b|$$

and

$$v_e = v_a + v_b$$

The F statistic is used to index the cumulative distribution function $Q(F|v_a, v_b)$ which gives the probability of that value or greater occuring by chance. If the un xplained variance (as a fraction of the xplained) is low, then F is small, and $Q(F|v_a, v_b|)$ is larg . In that case, the entities may be safely clustered.

In the described mbodiment of the pres nt invention lin s underg linear agglomerative clustering according to a test of their linear coherency. For all line or line-cluster pairs, if the pair passes the test of linear coherency, an F statistic based on an analysis of variance, is computed. The pair with the highest probability $Q(F|v_a, v_b)$ is merged. The parameters and limits of the merged line-cluster are recomputed using weighted linear regression. The whole cycle is repeated until no line-clusters pass the linear coherency test. An example of a set of line-clusters, following linear agglomerative clustering, is given in figure 9c.

2.1.1 Linear Coherency

Definitions:

Linearly coherent: Two lines or line-clusters are said to be linearly coherent if they could potentially form part of the same side of the rectangular signal/shadow boundary.

Linear agglomerative clustering: an iterative process for grouping together lines which are deemed (by some criteria) to be sufficiently similar. E.g. a pair-wise agglomerative clustering process based on an analysis of variance test, and broadly as described in (Silverman & Cooper), but with the mergable entities being lines rather than regions, and the constraint that two mergable regions be touching replaced by a constraint that two lines (or line-clusters) be linearly coherent.

In the described embodiment of the present invention the linear coherency test is applied to each line or line-cluster pair during linear agglomerative clustering. For two line or line-clusters to be viable candidates for clustering:

1. They must be approximately colinear.
2. Their extrapolations must overlap or touch.

2.1.1.1 Colinearity

Two line-clusters are determined as colinear if:

1. The line-clusters are approximately parallel:

$$\text{Min} \{Q^{(1)}_{WLR} - Q^{(2)}_{WLR} - 2e\pi\} < 15°$$

e in {-1,0,1}
and
2. The distance of closest approach between the two line-clusters is less than some threshold:
$d_c < 4$ pixels where the d_c are the distances depicted in figure 7.

2.1.1.2 Overlapping lines

Two line-clusters are said to have overlapping extrapolations if either has a perpendicular projection onto the other: see figure 8.

2.1.2 Analysis Of Variance

The F-statistic based upon the analysis of variance is applied to test the likelihood that two sample distributions come from the same parent distribution. With reference to the definition of analysis of variance, and weighted linear regression, the chi-squared variates are the sum of square errors of the best fit straight line:

$$\chi_j^2 = \lambda\_^{(j)}$$

where the line-cluster index j is any of a,b,m. The corresponding degrees of freedom are:

$$v_a = N_a - 2$$

$$v_b = N_b - 2$$

$$v_m = N_a + N_b - 2$$

where N_a and N_b are the numbers of edge-pixels in the lines (of labels a and b respectively).

Step iii) Building hypotheses

3.1. Search Tree

A search tree is constructed of all legal combinations of line-clusters : see figure 10a-h. The tree starts with a root node which corresponds to the null hypothesis that there is no collimation material present, and therefore that the signal/shadow boundary is absent. The addition of a new branch & node to the tree represents the addition of a further line-cluster to the hypothesis inherited from the parent node : each new node is associated with a new line-cluster. Therefore the return path from a particular node to the root determines the line-clusters in the hypothesis associated with that node.

The search tree has at most five levels, corresponding to the null hypothesis, and four levels for each of the four sides of the rectangular signal/shadow boundary. Each node represents a hypothesis in its own right.

As each node is added, the intermediate-level tests are applied to test the legality of the hypothesis. If the results are negative, then the node is flagged as illegal, excluded from further consideration, and the creation of offspring prohibited. Assuming all the hypotheses shown are legal, the example of figure 10 would result in a search tree in its final state as given in figure 11.

3.2. Intermediate-level tests

The following must be satisfied by each hypothesis during the construction of the search tree :

3.2.1. Orthogonality

All sides in a hypothesis must be approximately mutually orthogonal. Following addition of a new line-cluster at node n, this test is applied as :

$$\text{Min } \{|(Q^{(n)}{}_{WLR} - Q^{(p)}{}_{WLR} - k\pi/2|\} < 0.13$$

$$k \text{ in } \{-4..-1, 1...4\}$$

where the Q are in radians, and where p ranges over all nodes but n in the return path. If the new node fails this test, it is declared illegal.

3.2.2. Closure

All sides in a hypothesis must meet, at each end, either another side, or the edge of the image. Following the addition of a new line-cluster at node n, this test is applied by examining the limits of the new line-cluster at node n, and other line-clusters (at nodes p) in the return path which form an adjacent side of the rectangle.

Step iv) Testing and costing hypotheses

Once the hypothesis has been built, the intersection points for each of the sides of the candidate signal/shadow boundary are computed. These intersections may be either with the edge of the image, or with another side; see figure 9. The high level rules must then be satisfied in order that the hypothesis is verified.

4.1. Definition of terms and symbols

Image dimensions - Let th number of pixels in the image array be Imagewidth and Imageheight in the x and y

directions respectively.

Numb r of sides - L t the number of (visible) sides in the hypothesis be N (O ≤ N ≤ 4).

Intersection points - Let the intersection points of the kth side be (α_k, β_k) and (γ_k, δ_k) for the int rsections nearest the lower, and upper limits, l_k and u_k respectively.

Interval - Let the interval of the kth side b

$$\Delta_k = Max \{ |\alpha_k - \gamma_k|, |\delta_k - \beta_k| \} + 1.$$

RECTANGLE NOT SMALL - Let the signal/shadowboundary not be small if $\Delta_k >= 10$ for all k in {1..N}

Accumulated evidence - Let the accumulated evidence for the kth side be $W_k = \Sigma_j w_{k,j}$ where the sum is over all edge-points contributing to the kth side. Let the accumulated evidence for the kth interval be $W'_k = \Sigma_j w_{k,j}$ where the sum is over all edge-points contributing in the interval of the kth side.

EVIDENCE WELL USED - Let the amount of 'unused' evidence be small if: $W'_k/W_k >= 0.4$ for all k in {1..N}

Exposure statistics - Let max_k and $mean_k$ be the maximum and mean exposures (in the X-ray image) in the half-plane exterior to the kth side of the rectangle. Let max_{in} and $mean_{in}$ be the maximum and mean exposures in the interior (signal) part of the rectangle.

STRONG CONTRAST BOUNDARY - Let the boundary have strong contrast if : $(max_k - Min\{X(i,j)\})/(max_{in} - Min\{X(i,j)\}) < 0.65$ and $mean_k/mean_{in} < 1.05$ for all k in {1..N}

VERY STRONG CONTRAST BOUNDARY - Let the boundary have very strong contrast if :

$(max_k - Min\{X(i,j)\})/(max_{in} - Min\{X(i,j)\}) < 0.3$ and

$mean_k/mean_{in} < 1.05$ for all k in {1..N}

Line support - let pix_k be the number of pixels in the interval of the kth side, for which some evidence exists, ie for which $w_k \neq 0$.

PERSISTENT BOUNDARY - Let the boundary be persistent if :

$(pix_k + 2)/\Delta_k > 0.8$ for all k in {1..N}

VERY PERSISTENT BOUNDARY - Let the boundary be very persistent if : $(pix_k + 2)/\Delta_k > 0.88$ for all k in {1..N}

BOUNDARY HAS TWO ALIGNED SYMMETRIC SIDES - Let the boundary have two aligned symmetric sides if :

N = 2 and

$$\left\{ \underset{n \ in \ \{-1,0,1\}}{Min} \left\{ \left| Q^{(K)}_{WLR} - K\pi/2 - 2n\pi \right| \right\} \le 0.087 \right\} \quad \forall K \ in \ \{1,3\}$$

and

$$| R^{(3)}_{WLR} - R^{(1)}_{WLR} | / Imagewidth < 0.1$$

or
N = 2
and

$$\left\{ \underset{n \ in \ \{-1,0,1\}}{Min} \left\{ \left| Q^{(K)}_{WLR} - K\pi/2 - 2n\pi \right| \right\} \le 0.087 \right\} \quad \forall K \ in \ \{2,4\}$$

and

$$| R^{(4)}_{WLR} - R^{(2)}_{WLR} | / Imagewidth < 0.2$$

where th labels K = 1,2,3,4 corr spond to those lines having angl s with respect to the x axis, closest to $\pi/2$, π, $3\pi/2$, and 2π radians.

BOUNDARY HAS STRONG GESTALT - The boundary has strong gestalt if :

N = 4 or BOUNDARY HAS TWO ALIGNED SYMMETRIC SIDES

BOUNDARY HAS FOUR ALIGNED AND ROUGHLY SYMMETRIC SIDES - Tru if :

N = 4

and

$$\left\{ \begin{array}{c} \text{Min} \\ n \text{ in } \{-1,0,1\} \end{array} \left\{ \left| Q_{WLR}^{(K)} - K\pi/2 - 2n\pi \right| \right\} \leq 0.087 \right\} \quad \forall K \text{ in } \{1,4\}$$

and

$$\left| R_{WLR}^{(4)} - R_{WLR}^{(2)} \right| / \text{Imagewidth} < 0.2$$

and

$$\left| R_{WLR}^{(3)} - R_{WLR}^{(1)} \right| / \text{Imagewidth} < 0.2$$

BOUNDARY HAS TWO LONG ASPECT SYMMETRIC SIDES - True if :

N = 2

and Imageheight $\geq$ Imagewidth

and

$$\left\{ \begin{array}{c} \text{Min} \\ n \text{ in } \{-1,0,1\} \end{array} \left\{ \left| Q^{(K)} - K\pi/2 - 2n\pi \right| \right\} \leq 0.087 \right\} \quad \forall K \text{ in } \{1,3\}$$

and

$$\left| R_{WLR}^{(3)} - R_{WLR}^{(1)} \right| / \text{Imagewidth} < 0.1$$

or N = 2

and Imagewidth < Imageheight

and

$$\left\{ \begin{array}{c} \text{Min} \\ n \text{ in } \{-1,0,1\} \end{array} \left\{ \left| Q^{(K)} - K\pi/2 - 2n\pi \right| \right\} \leq 0.087 \right\} \quad \forall K \text{ in } \{2,4\}$$

and

$$\left| R_{WLR}^{(4)} - R_{WLR}^{(2)} \right| / \text{Imagewidth} < 0.1$$

BOUNDARY HAS VERY STRONG GESTALT - True if :

BOUNDARY HAS FOUR ALIGNED AND ROUGHLY SYMMETRIC SIDES or BOUNDARY HAS TWO LONG ASPECT SYMMETRIC SIDES

4.2. Verification rules

A hypothesis is accepted if the following composite rule is satisfied :

RECTANGLE NOT SMALL and EVIDENCE WELL USED and (BOUNDARY HAS VERY STRONG CONTRAST and BOUNDARY IS PERSISTENT or BOUNDARY HAS STRONG CONTRAST and BOUNDARY IS VERY PERSISTENT or BOUNDARY HAS VERY STRONG GESTALT and BOUNDARY IS PERSISTENT or BOUNDARY HAS VERY STRONG GESTALT and BOUNDARY HAS STRONG CONTRAST or BOUNDARY HAS STRONG GESTALT and BOUNDARY IS VERY PERSISTENT)

4.3. Costing hypotheses

If a hypothesis is rejected, it is awarded (effectively) an infinitely large cost. If the hypothesis is accepted however, it is awarded a cost which is determined as described below :

Let $p_{out} = 0.1$ be the fraction of pixels on the collimation/signal boundary which do not have a corresponding edge-pixel as determined by the Canny edge-detector.

Let $p_{in} = 0.1$ be the fraction of pixels which are co-linear with, but not on, a side of the collimation/signal boundary, yet which are labelled as edge-pixels by the Canny edge-detector.

Then the probability P_{in} of having k or more edge-pixels missing on a collimation/signal boundary of total interval (between intersects) n pixels is :

$$P_{in} = \sum_{s=k}^{n} \binom{n}{s} p^s q^{n-s} = Q(F \mid \upsilon_1, \upsilon_2)$$

where $q = 1-P_{in}$; $\upsilon_1 = 2(n-k+1)$; $\upsilon_2 = 2k$; $F = k(1-p_{in})/(n-k+1)$.

The same formula applies to the probability P_{out}, of there being k or more edge-pixels which are colinear with, but not on, sides of the collimation/signal boundary, of total interval between intersects n, and total interval between limits of L, provided :

$$q = 1-p_{out}; \upsilon_1 = 2(L-n-k+1); \upsilon_2 = 2k; F = k(1-p_{out})/(L-n-k+1).$$

The cost awarded is then :

$$4 - N + Min\{0.999 , -log(P_{in}P_{out})/100\}.$$

This function constrains the contribution from missing, and extra, edge-pixels to lie in [0,0.999]. The main part of the cost is determined by the number of sides : 0 for 4 sides, 1 for 3 sides, etc. The implicit rules area that :

1. Validated hypotheses are unconditionally cheaper for having more sides.
2. Given two hypothesis of equal number of sides, the cheapest is that which best explains the data.

Step v) Choosing the best hypothesis

The solution search tree is maintained by a branch and bound function. All possible hypotheses (potentially legal combinations of line-clusters) are considered. The hypothesis chosen by the system is that with the lowest cost, as awarded at step iv). If no other hypothesis is validated, the null hypothesis that there is not signal/shadow boundary (and therefore no shadow region) is always valid (with a cost of 4 units).

Figure 12 shows an embodiment of an exposure and read-out apparatus. A radiation image of an object was recorded on a photostimulable phosphor screen (6) by exposing (3) said screen to X-rays transmitted through the object. The irradiation field emitted by the X-ray source was limited by using a opaque X-ray shield (4).

The radiation image stored in the photostimulable phosphor scr en was read-out by scanning the phosphor screen with stimulating rays emitted by a laser (9). The stimulating rays w re deflected according to the main scanning dir ction by means of galvanometric deflection d vice (8). Th secondary scanning motion was p rform d by transporting the phosphor scr en in a direction indicated by arrow (7) perpendicular to the main scanning direction. The stimulated emission was directed by means of light collector (10) onto a photomultiplier (11) where it was conv rted into an electric signal representation. The analog output signal is then digitised (not shown).

This signal can then be subjected to a processing method according to the present invention for the purpose of determining the location of the signal-shadow boundary and hence also to the determination of the useful image region. Contrast enhancing processing can then be limited to the diagnostically useful image part.

Claims

1. A method for the determination of the location of the signal/shadow boundary in an X-ray image represented in a digital signal representation comprising the steps of :

   i) Extracting low-level primitives from the X-ray image {X(i,j)},
   ii) Forming a reduced number of intermediate-level primitives from the low-level primitives,
   iii) Building hypotheses being possible solutions regarding the location of the signal-shadow boundary, from combinations of intermediate-level primitives, during which each combination is subject to intermediate-level tests, whereupon partial or complete hypotheses are rejected or accepted,
   iv) Performing high-level verification tests on each hypothesis, whereupon hypotheses are rejected, or accepted at some cost, said cost defining a ranking of the acceptability of a hypothesis,
   v) Selecting the hypothesis with the least cost.

2. A method according to claim 1 wherein said low level primitives are lines.

3. A method according to claim 2 wherein said lines are extracted by performing on the digital signal representation the following steps:

   - subsampling,
   - performing edge detection on said subsampled image to produce the following intrinsic images:

     - squared local gradient magnitude {G(i,j)},
     - local edge orientation {O(i,j)},
     - edge image {E(i,j)}, in which all pixels having a squared gradient magnitude below a predetermined threshold value are set to zero, and in which all edge pixels which do not affect the local connectivity of other edge pixels have been removed by a thinning operation,
     - label image {L(i,j)}, in which all mutually connected edge pixels from the thinned edge image share a common, but otherwise unique label,
     - local edge orientation image, obtained by linear regression of connected edge pixels in a local neighbourhood,
     - vertex image {V(i,j)}, in which all edge pixels are identified to be one of the following vertex types: isolated point, terminal, edge point, T-junction, X-junction, curve point, or corner,
     - segment image {S(i,j)}, in which all edge pixels of vertex type 'edge point', as obtained from {V(i,j)}, are assigned the label of the corresponding pixel in {L(i,j)}, and the other pixels are zero,

   - extracting from {S(i,j)} pixels with identical labels,
   - creating line data structures for the purpose of representing lines, said data structures comprising fields for representing other line-specific data such as required by subsequent method steps and tests,
   - storing each set of coordinates of identically labelled pixels extracted from S{(i,j)} in a line data structure,
   - estimating for each of the line data structures the length of the corresponding line,
   - eliminating line data structures corresponding to all lines having a length smaller than some predetermined value from said line data structures,
   - determining the normal radius and orientation of each line by linear regression and recording those values in said line data structures as attributes of the corresponding line,
   - eliminating all line data structures for which the conformity to a straight line as determined by linear regression is below some predetermined value,

- lin arly extrapolating each non-eliminated lin from each nd, until it intersects either the image border or with an edg point as determined by {S(i,j)} which does not belong to that line, and recording in th line data structures the positions of both int rsection points as attributes of the corresponding lin .

4. A method according to claim 3 wher in said identification of the vertex type CORNER comprises

- curvature determination of connected chains of edge-pixels excluding pixels which are junctions or terminators,
- local non-maximum suppression of the curvature values,
- threshold of the remaining non-zero curvature values, accepting only those points as corners whose value is above some threshold.

5. A method according to claim 3 wherein said identification of the vertex type CURVE comprises

- curvature determination of connected chains of edge-pixels excluding pixels which are junctions or terminators,
- threshold of the curvature values, accepting only those points as curves whose value is above some threshold.

6. A method according to claim 3 wherein weighted linear regression comprises:

- calculation of weighted positional moments, upto second order, of edge-pixels in each line data structure, wherein the weighting of each pixel contribution at (i,j) is a function of the gradient magnitude G(i,j),
- use of the weighted moments to determine the parameters of the best fit straight line so as to minimise the weighted sum of squared errors (of pixel positions to the parameterised line).

7. A method according to claim 2 wherein said intermediate level primitives are line groups obtained by a linear agglomerative clustering process.

8. A method according to claim 7 wherein in the linear agglomerative clustering process any two lines or two line groups, or a line and a line group are merged into a single line group if:

- their difference of orientation is less than some predetermined value,
- their distance of closest approach is less than some predetermined value,
- they have overlapping extrapolations
- the outcome of the F-statistic based upon the analysis of variance is such that the two considered pixel distributions most likely belong to a single linear pixel distribution which constitutes the merged cluster.

9. A method according to claim 7, where candidate hypotheses for the signal/shadow boundary are formed from every possible line-group, pair of line-groups, triplet of line groups, and quartet of line-groups, including, in addition, the hypothesis that there is no signal/shadow boundary.

10. A method according to claim 7, wherein said high-level verification tests for the acceptability of a hypothetical signal/shadow boundary, comprise any logical combinations of the following tests for:

- boundary closure, for which test to be passed, for the hypothesis under consideration, the extrapolated line-groups must each terminate on, or intersect with, another line-group in the same hypothesis, or the edge of the image,
- boundary shape, for which test to be passed, for the hypothesis under consideration, is constrained to be rectangular, or nearly rectangular, or in the case of there being less than four sides in the hypothesis, the visible sides are constrained to be consistent with a partially visible rectangular or nearly rectangular shape,
- signal/shadow contrast, for which test to be passed, for the hypothesis under consideration, is constrained to be largely consistent with there being a lower level of exposure in the region of {X(i,j)} corresponding to the shadow region, than the level of exposure in the region of {X(i,j)} corresponding to the signal region,
- boundary location, for which test to be passed, for the hypothesis under consideration, the centre of the image must be either contained within the signal region, or must be close to a signal/shadow boundary,
- boundary alignment, for which test to be passed, for the hypothesis under consideration, each visible side of th rectangle must be parallel to a side of the image,
- boundary symmetry, for which test to be passed, for the hypothesis under consid ration, there must be two or four visible sides, which are aligned (as above), and approximately equidistant from the edge of the image.
- boundary completion, for which test to be passed, for the hypothesis under consideration, the fraction of the

boundary perimeter length, for which ther exists evidence from the low-level primitiv s, must be gr ater than some threshold.

11. A method according to claim 2 wherein a cost is assigned to each hypothesis, which cost is low st if the hypothesis is that of a rectangle with four sides visible, and which cost increas s as the number of visible sides of a rectangle in a hypothesis decreases, and the cost is highest if the hypothesis has no visible sides.

12. A method according to claim 11, for further refining the cost of each hypothesis, wherein the cost is increased according to the fraction of the signal/shadow boundary which is not supported by evidence from the low-level primitives.

13. A method according to any of the preceding claims wherein image processing performed on said digital signal representation of said X-ray image is limited to pixel values of said image within the signal/shadow boundary.

14. In a method of reading a radiation image stored in a photostimulable phosphor screen by scanning said screen with stimulating irradiation, detecting light emitted upon stimulation and converting the detected light into a digital signal representation a method of determining a signal/shadow boundary according to any of the preceding claims.

Patentansprüche

1. Ein Verfahren zur Bestimmung des Ortes der Signal-Schatten-Grenze in einem in einer digitalen Signaldarstellung dargestellten Röntgenbild, wobei das Verfahren folgende Schritte umfaßt:

   i) Ableiten von Grundelementen niedriger Stufe aus dem Röntgenbild $\{X(i,j)\}$,
   ii) Bilden einer verringerten Anzahl von Grundelementen der Zwischenstufe aus den Grundelementen niedriger Stufe,
   iii) Bilden von Hypothesen, die mögliche Lösungen hinsichtlich des Ortes der Signal-Schatten-Grenze sind, aus Kombinationen von Grundelementen der Zwischenstufe, während dessen jede Kombination Zwischenstufentests unterworfen wird, woraufhin teilweise oder vollständige Hypothesen verworfen oder akzeptiert werden,
   iv) jede Hypothese hochstufigen Überprüfungstests unterziehen, woraufhin Hypothesen verworfen oder unter gewissen Kosten akzeptiert werden, wobei die Kosten eine rangmäßige Einstufung der Akzeptierbarkeit einer Hypothese definieren,
   v) Auswahl der Hypothese mit den geringsten Kosten.

2. Verfahren nach Anspruch 1, wobei es sich bei den Grundelementen niedriger Stufe um Linien handelt.

3. Verfahren nach Anpruch 2, bei dem die Linien abgeleitet werden, indem an der digitalen Signaldarstellung die folgenden Schritte durchgeführt werden:

   - Unterabtastung,
   - Durchführung einer Randerfassung an dem unterabgetasteten Bild, um die folgenden intrinsischen Bilder herzustellen:

     - quadierte Größe $\{G(i,j)\}$ des örtlichen Gradienten,
     - örtliche Randausrichtung $\{O(i,j)\}$,
     - Randbild $\{E(i,j)\}$, in dem alle Bildpunkte mit einer quadrierten Gradientengröße unterhalb eines vorbestimmten Schwellwerts auf null gesetzt werden und bei dem alle Randbildpunkte, die sich nicht auf die örtliche Verknüpfbarkeit anderer Randbildpunkte auswirken, durch einen Ausdünnungsvorgang entfernt worden sind,
     - Markenbild $\{L(i,j)\}$, bei dem alle miteinander verbundenen Randbildpunkte von dem ausgedünnten Randbild eine gemeinsame, aber ansonsten eindeutige Marke gemeinsam haben,
     - örtliches Randausrichtungsbild, das durch lineare Regression verbundener Randbildpunkte in einer örtlichen Umgebung gewonnen worden ist,
     - Scheitelpunktbild $\{V(i,j)\}$, bei dem alle Randbildpunkte durch einen der folgenden Scheitelpunktarten identifiziert sind: isolierter Punkt, Endpunkt, Randpunkt, T-Verbindung, X-Verbindung, Kurvenpunkt oder Ecke,
     - Segmentbild $\{S(i,j)\}$, bei dem alle aus $\{V(i,j)\}$ erhaltenen Randbildpunkte vom Scheitelpunkttyp "Rand-

·punkt" der Marke des entsprechenden Bildpunktes in {L(i,j)} zugeordnet werden und die anderen Bildpunkte null sind,{L(i,j)}

- Ableiten von Bildpunkt n mit identischen Marken aus {S(i,j)},
- Erzeugen von Liniendatenstrukturen zum Zweck der Darst llung von Linien, wob i di Datenstrukturen Felder zum Darstellen anderer linienspezifischer Daten umfassen wie solche, die von darauffolgenden Verfahrensschritten und Prüfungen erfordert werden,
- Speichern jedes Satzes von Koordinaten von identisch markierten Bildpunkten, die aus {S(i,j)} abgeleitet worden sind, in einer Liniendatenstruktur;
- für jede der Liniendatenstrukturen Schätzen der Länge der entsprechenden Linie,
- Eliminieren von Liniendatenstrukturen, die allen Linien entsprechen, deren Länge geringer ist als ein vorbestimmter Wert, aus den Liniendatenstrukturen,
- Bestimmen des senkrechten Radius und der senkrechten Ausrichtung jeder Linie durch lineare Regression und Aufzeichnen dieser Werte in den Liniendatenstrukturen als Attribute der entsprechenden Linie,
- Eliminieren aller Liniendatenstrukturen, für die die durch lineare Regression bestimmte Konformität mit einer geraden Linie unterhalb eines gewissen vorbestimmten Wertes liegt,
- lineares Extrapolieren jeder nichteliminierten Linie von jedem Ende aus, bis sie entweder die Bildgrenze oder einen Randpunkt nach Bestimmung durch {S(i,j)}, der nicht zu dieser Linie gehört, schneidet, und Aufzeichnen der Positionen beider Schnittpunkte als Attribute der entsprechenden Linie in den Liniendatenstrukturen.

4. Verfahren nach Anspruch 3, bei dem die Identifizierung des Scheitelpunkts vom Typ ECKE folgendes umfaßt:

- Krümmungsbestimmung von verbundenen Ketten aus Randbildpunkten mit Ausnahme von Bildpunkten, bei denen es sich um Verbindungen oder Endpunkte handelt,
- örtliche nichtmaximale Unterdrückung der Krümmungswerte,
- Schwellwertbildung der verbleibenden, von null abweichenden Krümmungswerte, wobei lediglich solche Punkte als Ecken angenommen werden, deren Werte über einem gewissen Schwellwert liegen.

5. Verfahren nach Anspruch 3, bei dem die Identifizierung des Scheitelpunkts vom Typ KURVE folgendes umfaßt:

- Krümmungsbestimmung von verbundenen Ketten aus Randbildpunkten mit Ausnahme von Bildpunkten, bei denen es sich um Verbindungen oder Endpunkte handelt,
- Schwellwertbildung der verbleibenden Krümmungswerte, wobei lediglich solche Punkte als Kurven angenommen werden, deren Werte über einem gewissen Schwellwert liegen.

6. Verfahren nach Anspruch 3, bei dem die gewichtete lineare Regression folgendes umfaßt:

- Berechnung von gewichteten positionsmäßigen Momenten, bis zur zweiten Ordnung, von Randbildpunkten in jeder Liniendatenstruktur, wobei die Gewichtung jedes Bildpunktbeitrages bei (i,j) eine Funktion der Gradientengröße $G(i,j)$ ist,
- Verwendung der gewichteten Momente zur Bestimmung der Parameter der geraden Linie mit der besten Anpassung zur Minimierung der gewichteten Summe quadrierter Fehler (von Bildpunktpositonen zu der parametrisierten Linie).

7. Verfahren nach Anspruch 2, bei dem es sich bei den Grundelementen der Zwischenstufe um Liniengruppen handelt, die durch einen linear angehäuften Bündelungsprozeß erhalten worden sind.

8. Verfahren nach Anspruch 7, bei dem in dem linear angehäuften Bündelungsprozeß zwei beliebige Linien oder zwei Liniengruppen oder eine Linie und eine Liniengruppe in eine einzige Liniengruppe zusammengeführt werden, wenn:

- sie sich in ihrer Ausrichtung um weniger als einen gewissen vorbestimmten Wert unterscheiden,
- der Abstand bei ihrer nächsten Annäherung unter einem gewissen vorbestimmten Wert liegt,
- sie überlappende Extrapolierungen aufweisen,
- das Ergebnis der F-Statistik auf der Grundlage der Varianzanalyse derart ist, daß die zwei in Betracht gezogenen Bildpunktverteilungen, die am wahrscheinlichsten sind, zu einer einzigen linearen Bildpunktverteilung gehören, die das zusammengeführte Bündel ausmacht.

9. Vrfahren nach Anspruch 7, bei dem in Frage kommende Hypothesen für die Signal-Schatten-Grenz aus jeder möglichen Liniengrupp , jedem möglich n Paar von Liniengruppen, jedem möglichen Triple von Liniengruppen und jedem m¨glich n Quartett von Liniengruppen gebildet werden, und zwar außerdem inschließlich d r Hypothese, daß k ine Signal-Schatten-Gr nze vorliegt.

10. Verfahren nach Anspruch 7, bei dem die Verifikationsprüfungen auf hoher Stufe auf die Annehmbarkeit einer hypothetischen Signal-Schatten-Grenze alle beliebigen logischen Kombinationen von Prüfungen auf folgende Punkte umfassen:

- Grenzschließung, wobei bei der betrachteten Hypothese, um diese Prüfung zu bestehen, die extrapolierten Liniengruppen jeweils an einer anderen Liniengruppe in der gleichen Hypothese oder am Rand des Bildes enden müssen oder die Liniengruppe bzw. den Rand schneiden müssen,
- Grenzform, wobei bei der betrachteten Hypothese, um diese Prüfung zu bestehen, die Grenzform darauf eingeschränkt ist, rechtwinklig oder beinahe rechtwinklig zu sein, oder im Fall, daß in der Hypothese weniger als vier Seiten vorliegen, die sichtbaren Seiten eingeschränkt sind, um mit einer teilweise sichtbaren rechtwinkligen oder beinahe rechtwinkligen Form übereinzustimmen,
- Signal-Schatten-Kontrast, wobei bei der betrachteten Hypothese, um diese Prüfung zu bestehen, der Kontrast eingeschränkt ist, so daß er im großen und ganzen mit der Tatsache übereinstimmt, daß in dem Bereich von {X(i,j)}, der dem Schattenbereich entspricht, ein Grad an Belichtung vorliegt, der niedriger ist als der Belichtungsgrad in dem Bereich von {X(i,j)}, der dem Signalbereich entspricht,
- Grenzort, wobei bei der betrachteten Hypothese, um diese Prüfung zu bestehen, die Mitte des Bildes entweder im Signalbereich enthalten sein muß oder nahe an einer Signal-Schatten-Grenze liegen muß,
- Grenzausrichtung, wobei bei der betrachteten Hypothese, um diese Prüfung zu bestehen, jede sichtbare Seite des Rechtecks parallel zu einer Seite des Bildes verlaufen muß,
- Grenzsymmetrie, wobei bei der betrachteten Hypothese, um diese Prüfung zu bestehen, zwei oder vier sichtbare Seiten vorliegen müssen, die ausgerichtet sind (wie oben) und vom Rand des Bildes ungefähr äquidistant sind,
- Grenzvollendung, wobei bei der betrachteten Hypothese, um diese Prüfung zu bestehen, der Anteil der Grenzumfangslänge, für den Befund von den Grundelementen niedriger Stufe vorliegt, über einem gewissen Schwellwert liegen muß.

11. Verfahren nach Anspruch 2, wobei jeder Hypothese Kosten zugewiesen werden, wobei diese Kosten am niedrigsten sind, wenn es sich bei der Hypothese um ein Rechteck mit vier sichtbaren Seiten handelt, und wobei die Kosten mit der Abnahme der Anzahl der sichtbaren Seiten eines Rechtecks in einer Hypothese ansteigen und die Kosten am höchsten sind, wenn die Hypothese keine sichtbaren Seiten aufweist.

12. Verfahren nach Anspruch 11, zum weiteren Verfeinern der Kosten jeder Hypothese, wobei die Kosten gemäß demjenigen Anteil der Signal-Schatten-Grenze, der nicht durch Befund von den Grundelementen niedriger Stufe gestützt wird, ansteigen.

13. Verfahren nach einem der vorhergehenden Ansprüche, wobei die Bildverarbeitung, die an der digitalen Signaldarstellung des Röntgenbildes durchgeführt wird, auf Bildpunktwerte des Bildes innerhalb der Signal-Schatten-Grenze begrenzt ist.

14. Bei einem Verfahren zum Lesen eines in einem photostimulierbaren Leuchtstoffschirm gespeicherten Strahlungsbildes durch Abtasten des Schirms mit stimulierender Strahlung, Erfassen von bei der Stimulierung abgehendem Licht und Umwandeln des erfaßten Lichts in eine digitale Signaldarstellung, ein Verfahren zum Bestimmen einer Signal-Schatten-Grenze gemäß einem der vorhergehenden Ansprüche.

Revendications

1. Procédé de détermination de l'emplacement de la frontière signal/ombre dans une image radiographique représentée dans une représentation de signal numérique, comprenant les étapes consistant à:

   i) Extraire des primitiv s de bas niveau de l'imag radiographique {X(i,j)},
   ii) Former un nombre réduit de primitives de niveau intermédiaire à partir des primitives de bas niveau,
   iii) Elaborer des hypothèses comme solutions possibles relatives à l'emplacement de la frontière signal-ombre,

à partir de combinaisons de primitives de niveau intermédiaire, étape durant laquelle chaque combinaison st soumise à des tests de niveau intermédiaire, à la suite desqu ls des hypothèses partielles ou complètes sont rejeté s ou accepté s,

iv) Réaliser des tests de vérification de haut niveau sur chaque hypothèse, à la suite desquels des hypothèses sont rejetées ou acceptées à un certain coût, ledit coût définissant un classement de l'acceptabilité d'une hypothèse,

v) Sélectionner l'hypothèse de moindre coût.

2. Procédé selon la revendication 1, dans lequel lesdites primitives de bas niveau sont des lignes.

3. Procédé selon la revendication 2, dans lequel lesdites lignes sont extraites par réalisation des étapes suivantes sur la représentation de signal numérique:

   - sous-échantillonnage,
   - réalisation d'une détection de bords sur ladite image sous-échantillonnée pour produire les images intrinsè-ques suivantes:

     - carré de l'amplitude de gradient local $\{G(i,j)\}$,
     - orientation locale de bord $\{O(i,j)\}$,
     - image de bord $\{E(i,j)\}$, dans laquelle tous les pixels dont le carré de l'amplitude de gradient est inférieur à une valeur seuil prédéterminée sont fixés à zéro, et dans laquelle tous les pixels de bord qui n'affectent pas la connectivité locale d'autres pixels de bord ont été supprimés par une opération d'allègement,
     - image de désignation $\{L(i,j)\}$, dans laquelle tous les pixels de bord mutuellement connectés de l'image de bord allégée partagent une désignation commune, quoique autrement unique,
     - image d'orientation locale de bord, obtenue par régression linéaire de pixels de bord connectés dans un voisinage local,
     - image de sommets $\{V(i,j)\}$, dans laquelle tous les pixels de bord sont identifiés comme étant l'un des types de sommet suivants: point isolé, terminaison, point de bord, jonction en T, jonction en X, point de courbe, ou coin,
     - image de segment $\{S(i,j)\}$, dans laquelle on attribue à tous les pixels de bord du type de sommet 'point de bord', tels qu'obtenus à partir de $\{V(i,j)\}$, la désignation du pixel correspondant dans $\{L(i,j)\}$, et les autres pixels ont pour valeur zéro,

   - extraction de $\{S(i,j)\}$ des pixels ayant des désignations identiques,
   - création de structures de données de lignes dans le but de représenter des lignes, lesdites structures de données comprenant des champs pour représenter d'autres données spécifiques à des lignes, nécessaires pour des étapes et des tests ultérieurs du procédé,
   - mémorisation de chaque ensemble de coordonnées de pixels désignés de manière identique, extraits de $S\{(i,j)\}$, dans une structure de données de lignes,
   - estimation, pour chacune des structures de données de lignes, de la longueur de la ligne correspondante,
   - élimination desdites structures de données de lignes les structures de données de lignes correspondant à toutes les lignes dont la longueur est inférieure à une certaine valeur prédéterminée,
   - détermination du rayon normal et de l'orientation de chaque ligne par régression linéaire et enregistrement de ces valeurs dans lesdites structures de données de lignes en tant qu'attributs de la ligne correspondante,
   - élimination de toutes les structures de données de lignes pour lesquelles la conformité par rapport à une droite, telle que déterminée par régression linéaire, est inférieure à une certaine valeur prédéterminée,
   - extrapolation linéaire de chaque ligne non éliminée depuis chaque extrémité, jusqu'à ce qu'elle coupe soit la frontière de l'image, soit un point de bord tel que déterminé par $\{S(i,j)\}$, qui n'appartient pas à cette ligne, et enregistrement, dans les structures de données de lignes, des positions des deux points d'intersection en tant qu'attributs de la ligne correspondante.

4. Procédé selon la revendication 3, dans lequel ladite identification du type de sommet COIN comprend

   - la détermination de la courbure de chaînes connectées de pixels de bord, à l'exclusion des pixels qui sont des jonctions ou des pixels terminaux,
   - la suppresion locale non maximale des valeurs de courbure,
   - la fixation d'un seuil pour les valeurs de courbure non nulles restantes, en acceptant en tant que coins uni-quement les points dont la valeur est supérieure à un certain seuil.

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5. Procédé selon la revendication 3, dans lequel ladite identification du typ de sommet COURBE comprend

- la détermination d la courbure de chaînes connectées de pixels de bord, à l'exclusion d s pix ls qui sont des jonctions ou des pixels terminaux,
- la fixation d'un seuil pour les valeurs de courbure, en acceptant en tant que courbes uniquement les points dont la valeur est supérieure à un certain seuil.

6. Procédé selon la revendication 3, dans lequel la régression linéaire pondérée comprend:

- le calcul de moments de position pondérés, jusqu'au deuxième ordre, de pixels de bord dans chaque structure de données de ligne, dans lequel la pondération de chaque contribution de pixel en (i,j) est une fonction de l'amplitude de gradient G(i,j),
- l'utilisation des moments pondérés pour déterminer les paramètres de la droite de meilleur ajustement de manière à minimiser la somme pondérée du carré des erreurs (des positions des pixels par rapport à la ligne paramétrée).

7. Procédé selon la revendication 2, dans lequel lesdites primitives de niveau intermédiaire sont des groupes de lignes obtenus par une méthode de mise en faisceaux linéaire agglomérante.

8. Procédé selon la revendication 7, dans lequel, dans la méthode de mise en faisceaux linéaire agglomérante, deux lignes ou deux groupes de lignes, ou une ligne et un groupe de lignes quelconques sont fusionnés en un groupe de lignes unique si:

- leur différence d'orientation est inférieure à une certaine valeur prédéterminée,
- leur distance d'approche minimale est inférieure à une certaine valeur prédéterminée,
- ils ont des extrapolations en chevauchement
- le résultat de la statistique F basé sur l'analyse de la variance est tel que les deux distributions de pixels considérées appartiennent très probablement à une distribution de pixels linéaire unique qui constitue le faisceau fusionné.

9. Procédé selon la revendication 7, où des hypothèses candidates pour la frontière signal/ombre sont élaborées à partir de chaque groupe de lignes, paire de groupes de lignes, triplet de groupes de lignes, et quadruplet de groupes de lignes possibles, y compris, en outre, l'hypothèse qu'il n'y a aucune frontière signal/ombre.

10. Procédé selon la revendication 7, dans lequel lesdits tests de vérification de haut niveau d'acceptabilité d'une frontière signal/ombre hypothétique, *comprennent toute combinaison logique des tests suivants de:*

- fermeture de la frontière; pour qu'un tel test soit passé avec succès, pour l'hypothèse considérée, les groupes de lignes extrapolés doivent chacun aboutir sur, ou couper, un autre groupe de lignes dans la même hypothèse, ou le bord de l'image,
- forme de la frontière; pour qu'un tel test soit passé avec succès, pour l'hypothèse considérée, on contraint la forme à être rectangulaire, ou pratiquement rectangulaire ou, dans le cas où il y a moins de quatre côtés dans l'hypothèse, on contraint les côtés visibles à être compatibles avec une forme rectangulaire ou pratiquement rectangulaire partiellement visible,
- contraste signal/ombre; pour qu'un tel test soit passé avec succès, dans l'hypothèse considérée, on contraint le contraste à être largement compatible avec le fait qu'il y ait un niveau d'exposition dans la région de {X(i, j)} correspondant à la région d'ombre, inférieur au niveau d'exposition dans la région de {X(i,j)} correspondant à la région de signal,
- emplacement de la frontière; pour qu'un tel test soit passé avec succès, pour l'hypothèse considérée, le centre de l'image doit être soit contenu à l'intérieur de la région de signal, soit être proche d'une frontière signal/ombre,
- alignement de la frontière; pour qu'un tel test soit passé avec succès, pour l'hypothèse considérée, chaque côté visible du rectangle doit être parallèle à un côté de l'image,
- symétrie de la frontière; pour qu'un tel test soit passé avec succès, pour l'hypothèse considérée, il doit y avoir deux ou quatre côtés visibles, qui soient alignés (comme ci-dessus), et approximativement équidistants du bord de l'image,
- achèvement de la frontière; pour qu'un tel test soit passé avec succès, pour l'hypothèse considérée, la fraction de la longueur du périmètre de la frontière, pour laquelle il existe des preuves provenant des primitives de bas niveau, doit être supérieure à un certain seuil.

11. Procédé selon la revendication 2, dans lequel un coût est attribué à chaque hypothèse, lequel coût est le moins élevé si l'hypothèse est celle d'un rectangle ayant quatre côtés visibles, et lequel coût augmente à mesure que le nombre de côtés visibles d'un rectangle dans une hypothèse diminue, et le coût est le plus élevé si l'hypothèse n'a aucun côté visible.

12. Procédé selon la revendication 11, en vue d'affiner le coût de chaque hypothèse, dans lequel le coût est augmenté selon la fraction de la frontière signal/ombre qui n'est pas appuyée par des preuves provenant des primitives de bas niveau.

13. Procédé selon l'une quelconque des revendications précédentes, dans lequel le traitement de l'image réalisé sur ladite représentation de signal numérique de ladite image radiographique est limité aux valeurs de pixels de ladite image à l'intérieur de la frontière signal/ombre.

14. Dans un procédé de lecture d'une image de rayonnement mémorisée dans un écran luminescent photostimulable par balayage dudit écran avec un rayonnement de stimulation, détection de la lumière émise suite à la stimulation, et conversion de la lumière détectée en une représentation d'image numérique, procédé de détermination d'une frontière signal/ombre selon l'une quelconque des revendications précédentes.
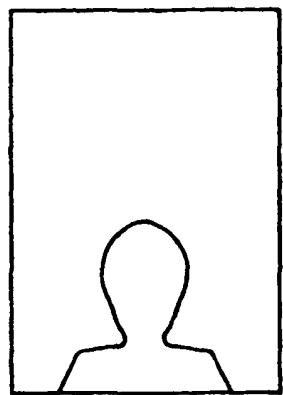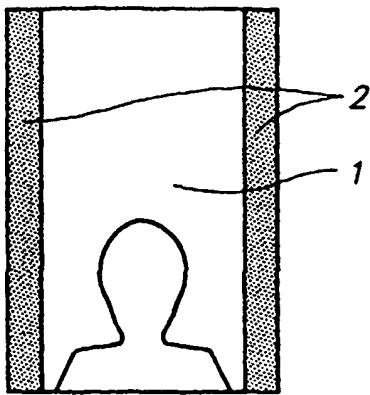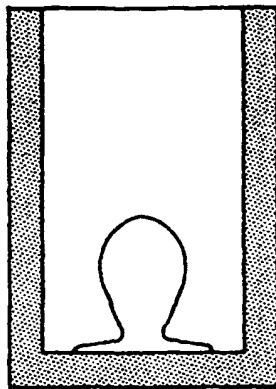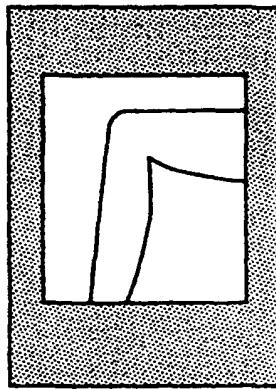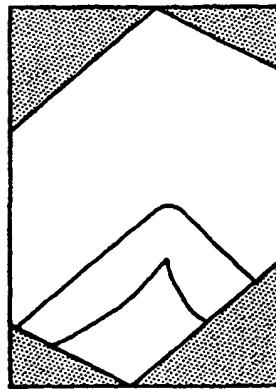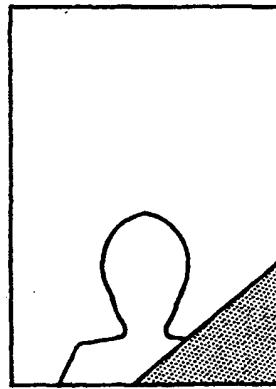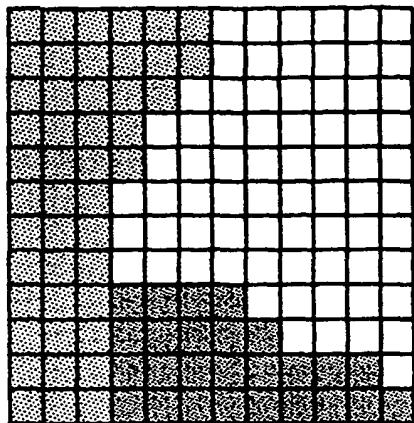
FIG. 1

(a) original image
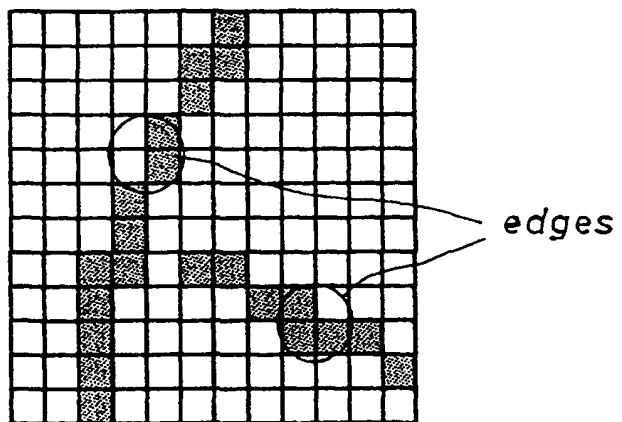
(b) edge image

FIG. 2

FIG. 3

edge image
after thinning
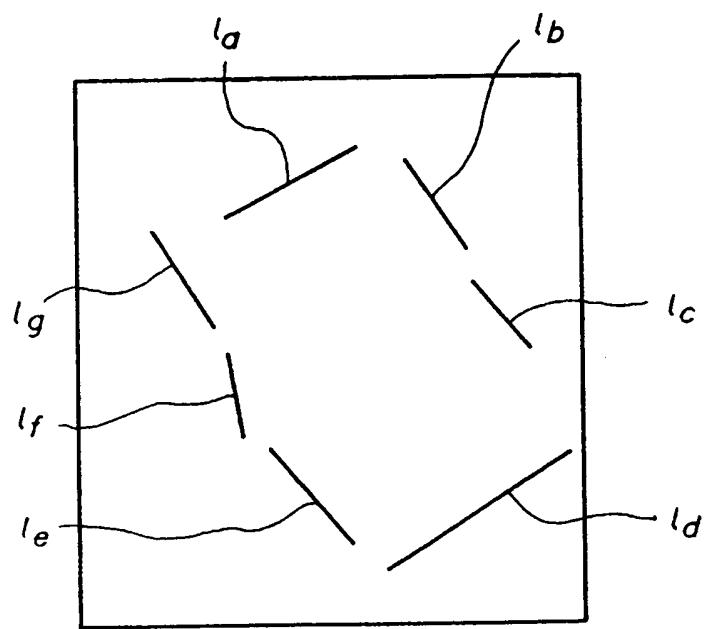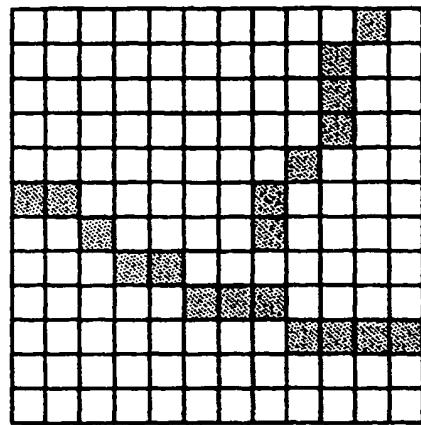
edge image
before thinning

FIG. 4

FIG. 5

FIG. 6

d_c

(a)

d_c

(b)

d_c

(c)
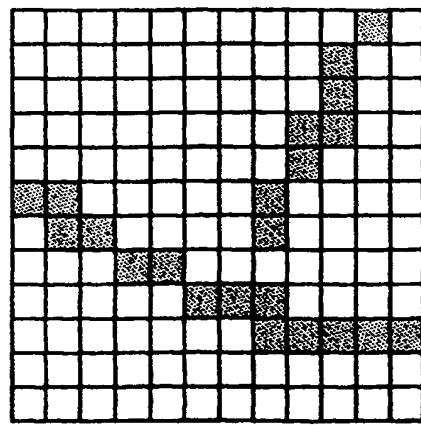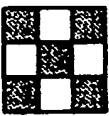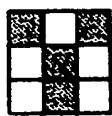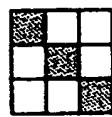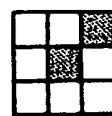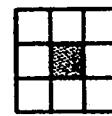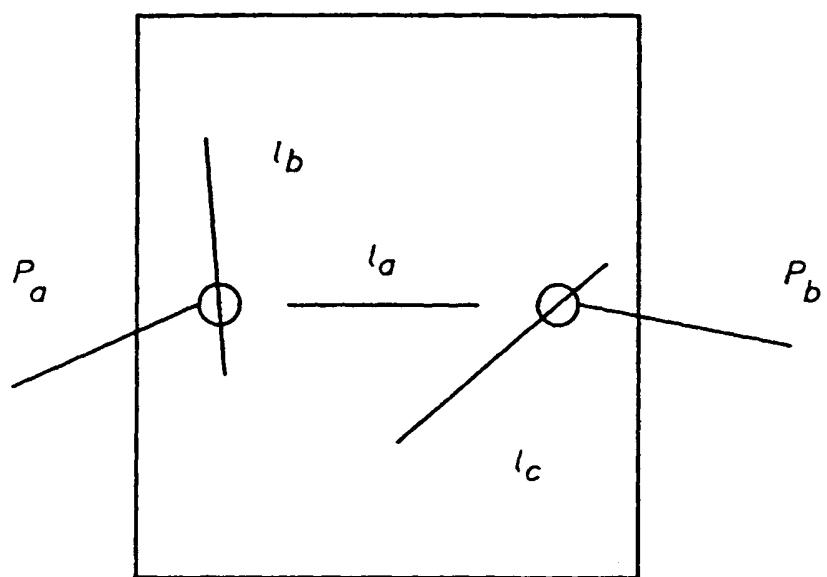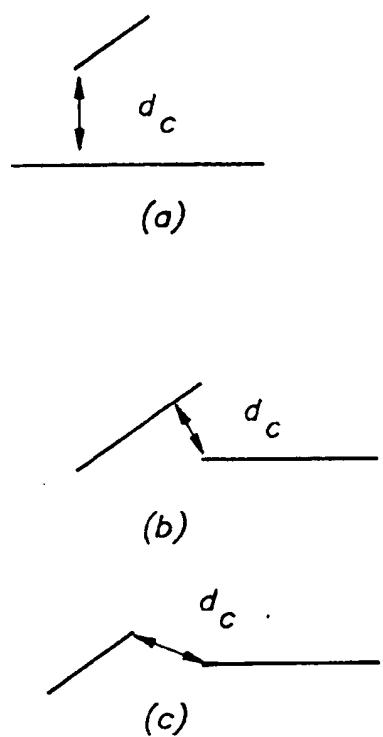
FIG. 7
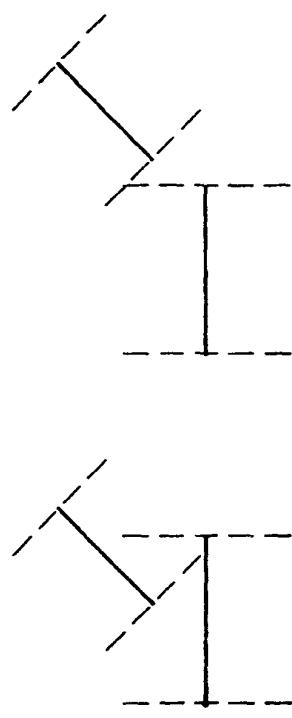
no overlap
zero orthogonal projection

lines overlap

FIG. 8

(a)

(b)

(c)

FIG. 9

shadow region

signal region

(a)　　　(b)　　　(c)　　　(d)　　　(e)　　　(f)　　　(g)　　　(h)

FIG. 10

FIG. 11

FIG. 12